Accelerators Report

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Organization and Mission

The NSLS Accelerator Division (AD) was established in late 2001 through the reorganization of the NSLS and is headed by James B. Murphy. The division is organized into two sections: the Linear Accelerator (Linac) Section, headed by Xijie Wang, and the Storage Ring & Insertion Device Section, headed by Boris Podobedov. The staff consists of eight accelerator physicists, two engineers, three technicians, and two postdocs.

The NSLS Accelerator Division (AD) has a four-part mission:

- To ensure the quality of the electron beam in the existing NSLS booster, linear accelerator, and x-ray and vacuum ultraviolet (VUV) storage rings
- To operate the deep ultraviolet free electron laser (DUV-FEL) and Magnet Measurement facilities
- To participate in the NSLS-II project
- To perform fundamental research and development in accelerator and free electron laser physics

2003 Activities

NSLS-II: A major activity of the AD staff was the initial design of the new storage ring source for the NSLS-II project. The AD staff worked in conjunction with the other divisions of the NSLS to develop the machine concept for an ultra-high brightness ($\sim 10^{21}$) 3 GeV electron storage ring design. The preliminary design is based on a 24-cell triple bend achromat lattice with a horizontal emittance in the range of 1.5 nm (**Figure 1**). Such a ring would more than triple the number of insertion devices available to the user community and provide 10,000 times higher brightness. A machine advisory committee was established to provide feedback on the machine design.

Storage Rings: Significant effort by the AD staff went into studying how the installation of more Mini Gap Undulators (MGU) in the x-ray ring would affect accelerator performance. In particular, MGUs may limit the beam current due to various collective effects induced by the strong impedance of the mini-gap chamber and transitions. The recent installation of the X29 MGU chamber gave us an opportunity to measure and compare some of these effects before and after the installation. While we did observe increased betatron tuneshifts with current at low energy, fortunately the increase turned out to be quite small and should not hinder operations. Single bunch currents of up to 125 mA are still possible, with the (administrative) limit set due to heat in vacuum chamber components unrelated to MGUs. We are also numerically calculating the impedance of the MGU chamber with electromagnetic field simulators. These studies should also provide valuable insights into the possible effect of MGUs on the future performance of the NSLS-II storage ring.

Another area of activity emphasized improvements to the storage ring lattices of the X-ray and VUV rings. The LOCO code, originally developed at the NSLS by James Safranek, allows calibrating and correcting the ring lattice from the measured beam response matrix. With James' help, a new, more powerful MATLAB-based version of this code was extensively debugged at the NSLS last year and is now used for both rings. This work has also shown some limitations of our existing diagnostics and resulted in the installation of new Hall probes into some of the X-ray ring magnets.

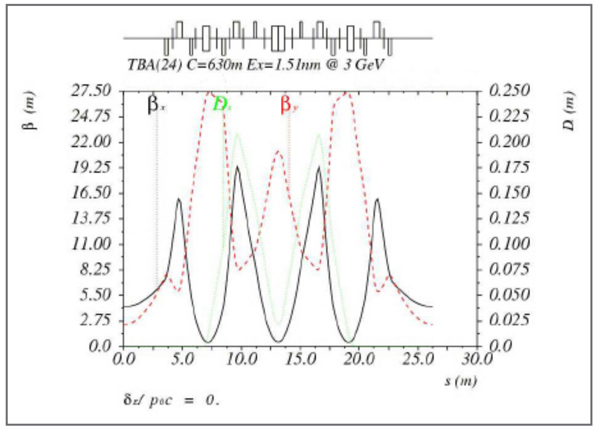

Figure 1. Storage ring lattice functions for the preliminary design of the NSLS-II ring (β_x in black, β_y in red and D_x in green).

Other work on the VUV ring included setting up shorter electron bunch configurations for time-resolved experiments as requested by the IR users. The challenge is to get a stable configuration of the ring lattice and RF system (with the harmonic cavity set for compression) that produces short bunches at substantial beam currents. Bunch lengths on the order of 400 ps FWHM with ~100 mA/bunch have been achieved. Work is continuing on yet another challenging configuration that produces mm-scale periodic ~10 Hz orbit motion at beamline U4IR while keeping stable orbit throughout the rest of the ring. This motion fills the very-far IR spectral gaps that are produced by the interference between the direct synchrotron radiation and (orbit-dependent) reflections off the walls of the vacuum chamber. To provide for the very localized orbit distortion, we are reconfiguring the VUV ring digital orbit feedback system.

Magnetic Measurement Lab: Early in FY 2003, a second in-vacuum, mini-gap undulator (designated MGU-29) was assembled, measured, and magnetically shimmed to minimize magnetic field errors and to optimize its spectral performance. The Mechanical Group installed it in the X-ray ring in the space between a pair of accelerating cavities in the X29 straight section. The magnet gap was left open to temporarily reduce the x-ray output to a negligible amount pending installation of front-end and optical components of the new NIH-funded protein crystallography beamline. These components were installed in the winter 2003-04 shutdown.

An FY 2002 design study to replace the aging X1 soft x-ray undulator identified several options that were presented to the X1 users and User Science Division staff. The preferred option was a pair of 1.4 m long undulators in tandem, canted to produce two photon beams, separated by about 1 milliradian, serving beamlines X1A and X1B independently, with independent control of each device by the respective users. One device would be a variable-polarization undulator, the other a planar one. However, this solution was predicated on a significant reduction of the height of the vacuum chamber in these devices. To verify the impact of a reduced chamber height on machine operations, particularly during injection, and to determine the minimum allowed vertical aperture in the new undulators, we decided to experimentally simulate the reduced aperture. A motorized beam scraper assembly was refurbished and installed in a chamber to be shared with an existing photon absorber, just upstream of the MGU-13 in-vacuum undulator. The combination of the variable-gap MGU-13 in the center of the straight and the scraper, approximately one meter upstream, will allow the characterization of the vertical beam profile in a typical straight section under all operating conditions. This scraper assembly was installed during the December 2003 shutdown.

As an important part of our efforts to develop a superconducting undulator (SCU), a state-of-the-art SCU measurement apparatus was designed by the Magnetic Measurement and Mechanical Engineering staff, and is now under construction (**Figure 2**). It is designed to perform both magnetic and calorimetric measurements on SCU models up to about 0.4 m in length, cooled either by immersion in liquid helium (LHe) or by conduction. Three independently instrumented helium channels will allow detailed calorimetric measurement of both the SCU magnet windings and the beampipe under various thermal conditions, including simulated beam heating. A motorized, multi-element Hall sensor assembly for detailed magnetic field mapping has been constructed and bench-tested. The Hall sensors will be calibrated off-line against an NMR standard in a laboratory magnet, both at room temperature and at 77K in a liquid nitrogen bath. A small superconducting magnet within the cryostat will also permit in-situ calibration checks of the sensors at 4K. The Hall probe mapper will be interchangeable with a stretched wire sensor, instrumented to operate in either the pulsed-wire or vibrating-wire mode, and will provide complementary measurements of field errors, trajectory errors, and integrated field errors.

Figure 2. Vertical Test Facility for magnetic measurements of future superconducting undulators.

Together with the BNL Magnet Division, we plan to develop a SCU design using advanced "APC-type" NbTi superconductors, which can operate at higher currents and fields than conventional NbTi. We also plan to investigate a means of correcting phase errors in SCU's, critical for achieving high brightness at high harmonics for full coverage of the 2-20 keV photon range.

An improved magnetic design was developed for a new in-vacuum undulator to replace the aging X25 wiggler. The new device, designated "MGU-25," will be one meter long with an 18 mm period and a minimum gap of 5.6 mm, and will cover 1.9 – 20 keV, using the fundamental, 2nd (present due to the rather high emittance), 3rd, 5th, and 7th harmonics. The latest NdFeB materials with higher remanent field and very high intrinsic coercivity will be used to maximize the tuning range. The Mechanical Engineering group designed a longer vacuum chamber and a "twin-tower" support structure derived from the successful "single-tower" and chamber designs used in MGU-13 and MGU-29. A make-or-buy decision, development of detailed specifications, and procurement of just the magnets or the complete undulator are expected in FY 2004.

We continued our collaboration with A. Temnykh of Cornell in developmenting a vibrating-wire magnetic probe for use in small-gap undulators. This technique will be adapted for insertion into the SCU test apparatus described above. Magnetic Measurement staff also supported the Cascaded High-Gain Harmonic Generation X-ray FEL proposal by modeling and developing wiggler designs for the five modulator and amplifier stages. Magnetic Measurement staff contributed to the development of the NSLS-II lattice design via 3D magnetic modeling of candidate magnet designs, such as combined-function gradient dipole electromagnets and permanent magnet-driven gradient dipoles.

DUV-FEL: The Deep Ultra Violet Free Electron Laser (DUV-FEL) provides unique capabilities to the NSLS user community. The accelerator system of the DUV-FEL consists of a 1.6-cell BNL photo injector driven by a Ti:Sapphire laser system, and a four section 2856 MHz SLAC-type traveling wave linac capable of producing a 200 MeV electron beam. The magnetic chicane bunch compressor at the DUV-FEL produces sub picosecond (ps) long electron bunches with a peak current of a few hundred amperes. The high brightness electron beam transits the 10 meter long NISUS undulator to generate UV light with a fundamental wavelength of 266 nanometers (nm).

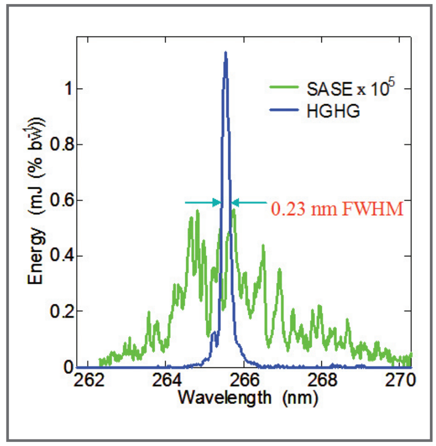

Figure 3. Experimental comparison between unsaturated Self Amplified Spontaneous Emission (SASE) and High Gain Harmonic Generation (HGHG) spectra.

In FY03, the DUV-FEL achieved a unique mode of operation known as High Gain Harmonic Generation (HGHG), whereby the electron beam is energy modulated with the Ti:Sapphire laser at 800 nm, the energy modulation is converting into spatial bunching in a dispersive magnet, and then the bunched electron beam radiates coherently at 266 nm in the NISUS undulator.

After successfully lasing at 266 nm with the 800 nm laser seeding, experiments were carried out at the DUV-FEL to further characterize the properties of the HGHG FEL, and to demonstrate its stability and controllability. The narrower spectrum and better stability of HGHG compared to a SASE FEL were observed (**Figure 3**). Both the second and the third harmonic of the HGHG FEL radiation were experimentally characterized using a vacuum monochromator. The pulse energy for both harmonics (133 and 89 nm) was measured to be about 1 μJ, which is about 1% of the fundamental at 266 nm. A two-photon absorption auto-correlator with 100 fs resolution was developed to characterize the HGHG output pulse length. It was experimentally demonstrated that the HGHG output pulse length can be controlled using the seed laser from a picosecond down to 250 fs (FWHM). Experiments to investigate a chirped HGHG FEL were also initialized in 2003. Preliminary results are very promising, and the chirped FEL could lead to even shorter pulses of HGHG output.

One of the most important milestones in the last year at the DUV-FEL is the initialization and completion of the first DUV-FEL user experiment by Arthur Suits and his collaborators from the BNL Chemistry Department. The first chemical science experiment – ion pair imaging – used the third harmonic (89 nm) of the HGHG output to study the super excited states of methyl fluoride. Velocity mapped ion images of the fluoride ion, obtained with excitation via intense, coherent, sub-picosecond pulses of 86-89 nm radiation, reveal low translational energy, implying very high internal excitation in the methyl cation cofragment (**Figure 4**). The report on this experiment has been published in Physical Review Letters. To advance the user science program at the DUV-FEL, the NSLS hosted a very productive chemical science user workshop in July 2003.

There is increasing interest in high intensity THz radiation because of its potential applications in homeland security and material characterization. Two experiments were performed at the DUV-FEL to explore the possibility of using the bright electron beam to generate coherent THz radiation. In the first experiment, the electron beam with a sub-mm modulation was produced via temporal modulation of the photoinjector drive laser. The spatially modulated electron beam then is used to generate coherent THz radiation. Pulses in excess of 80 μJ of coherent THz radiation, using a transition radiation mechanism, were measured in the second experiment using sub-picosecond electron bunches containing about 0.7 nano-coulombs of charge. This intensity is about two orders of magnitude higher than the laser-based THz sources, and field strengths on the order 500 kV/cm are expected from such an intense THz source.

High-brightness electron beam generation and preservation is the key to the success of all future linac-based light sources. Investigations performed at the DUV-FEL revealed the possibility of strong longitudinal spatial modulation driven by a space-charge oscillation during the electron beam bunch compression. Comparison between experiments and simulation confirmed the amplification of an existing modulation during bunch compression. A femtosecond electron bunch monitor based on the electron-optical effect was successfully commissioned at the DUV-FEL to study the electron beam longitudinal distribution and the timing jitter between the electron beam and the HGHG seed laser. Using this technique, the timing jitter between the electron beam and the HGHG seed laser was measured to be 150 fs.

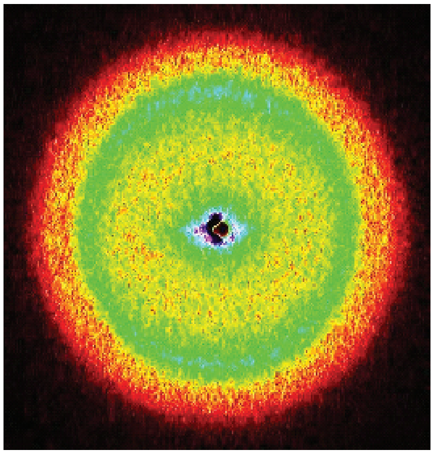

Figure 4. Ion pair image from the first DUV-FEL user experiment.

Beam Line Operations and Safety Awareness (BLOSA) training and many other procedures were developed at the DUV-FEL to improve acceleration operation and laser safety.

In September 2003, Dr. L.H. Yu of the NSLS Accelerator Division was awarded the 2003 International FEL Prize for his outstanding contributions to “High Gain Free Electron Lasers and High Gain Harmonic Generation.”